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(54) **HIGH-SPEED TURBO DECODER**

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(52) **U.S. Cl.** **714/796**; 714/794
(58) **Field of Search** 714/786, 794, 714/796

(56) **References Cited**

U.S. PATENT DOCUMENTS

Re. 32,905		4/1989	Baran .	
5,349,589		9/1994	Chennakeshu et al. .	
5,406,570		4/1995	Berrou et al. .	
5,446,747		8/1995	Berrou .	
5,721,745	*	2/1998	Hladik et al.	714/755
5,721,746	*	2/1998	Hladik et al.	714/792
5,734,962	*	3/1998	Hladik et al.	455/12.1
6,000,054	*	12/1999	Bahr et al.	714/786
6,014,411	*	1/2000	Wang	375/259
6,023,783	*	2/2000	Divsalar et al.	714/792
6,028,897	*	3/2000	Wang	375/265
6,044,116	*	2/2000	Wang	375/265

FOREIGN PATENT DOCUMENTS

0 735 696 10/1996 (EP) .
2 675 970 10/1992 (FR) .

OTHER PUBLICATIONS

D. Divsalar and F. Pollara, "Hybrid Concatenated Codes and Iterative Decoding", TDA Progress Report 42–130, Jet Propulsion Laboratory, NASA, Aug. 15, 1997.*
S. Benedetto, D. Divsalar, G. Montorsi, and F. Pollara, "A Soft–Input Soft–Output Maximum A Posteriori MAP Module to Decode Parallel and Serial Concatenated Codes", TDA Progress Report 42–127, Jet Propulsion Laboratory, NASA, Nov. 15, 1996.*
Patrick Robertson, Emmanuelle Villebrun and Peter Hoecher, "A Comparison of Optimal and Sub–Optimal MAP Decoding Algorithms Operating in the Log Domain", IEEE 1995.*

(List continued on next page.)

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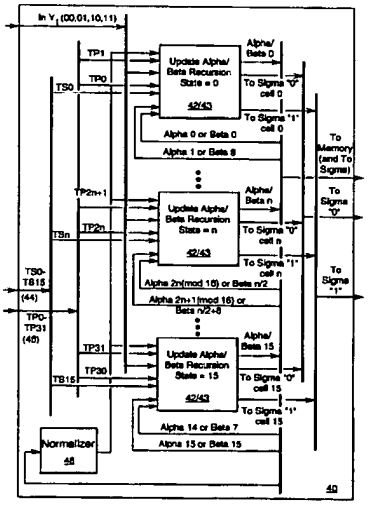
(57) **ABSTRACT**

A high-speed turbo decoder utilizes a MAP decoding algorithm and includes a streamlined construction of functional units, or blocks, amenable to ASIC implementation. A gamma block provides symbol-by-symbol a posteriori state transition probability estimates. Two gamma probability function values are provided via selection switches to the alpha and beta blocks for calculating the alpha and beta probability function values, i.e., performing the alpha and beta recursions, respectively, in parallel, thus significantly increasing decoding speed. A scaling circuit monitors the values of the alpha and beta probability functions and prescribes a scale factor such that all such values at a trellis level remain within the precision limits of the system. A sigma block determines the a posteriori state transition probabilities (sigma values) and uses the sigma values to provide soft-decision outputs of the turbo decoder.

1 Claim, 16 Drawing Sheets



OTHER PUBLICATIONS

Patrick Robertson, "Illuminating the Structure of Code and Decoder of Parallel Concatenated Recursive Systematic Turbo Codes", IEEE 1994.*

Patrick Robertson, "Improving Decoder and Code Structure of Parallel Concatenated Recursive Systematic Turbo Codes", IEEE 1994.*

Sven Riedel, "MAP Decoding of Convolutional Codes Using Reciprocal Dual Codes", IEEE Transactions on Information Theory, vol. 44, No. 3, May 1998.*

S. Benedetto, D. Divsalar, G. Montorsi and F. Pollara; "Soft-Output Decoding Algorithms in Iterative Decoding of Turbo Codes"; TDA Progress Report 42–124, Jet Propulsion Laboratory, NASA, Feb. 15, 19.*

Jakob Dahl Andersen, "The Turbo Coding Scheme", Report IT–146, ISSN 0105–854, Institute of Telecommunication, Technical University of Denmark, Dec. 1994.*

Claude Berrou and Alain Glavieux, "Near Optimum Error Correcting Coding And Decoding: Turbo–Codes", IEEE Transactions on Communications, vol. 44, No. 10, Oct. 1996.*

Sven Riedel, "Symbol–by–Symbol MAP Decoding Algorithm for High–Rate Convolutional Codes That Use Reciprocal Dual Codes", IEEE Journal on Selected Areas in Communications, vol. 16, No. 2, Feb. 1998.*

"Turbo Code Decoder with Controlled Probability Estimate Feedback," JAF Ross; SM Hladik; NA VanStralen, JB Anderson, Ser. No. 09/137,257 (GE docket RD–25781), filed Aug. 20, 1998.

"Turbo Code Decoder with Modified Systematic Symbol Transition Probabilities," SM Hladik; JAF Ross; NA VanStralen; Ser. No. 09/137,256 (GE docket RD–26016), filed Aug. 20, 1998.

"A Maximum a Posteriori Estimator with a Fast Sigma Calculator," JAF Ross; AM Itani; NA VanStralen; SM Hladik; Ser. No. 09/137,260 (GE docket RD–26035), filed Aug. 20, 1998.

"High–Data Rate Maximum a Posteriori Decoder for Segmented Trellis Code Words," SM Hladik; NA VanStralen; JAF Ross; Ser. No. 09/137,181 (GE docket RD–26064), filed Aug. 20, 1998.

"Source and Channel Coding, an Algorithmic Approach," John B. Anderson; Seshadri Mohan, pp. 216, 336–342.

"Decision Depths of Convolutional Codes," John B. Anderson; Kumar Balachandran; IEEE Transactions on Information Theory, vol. 35, No. 2, Mar. 1989, pp. 455–459.

"The Turbo Coding Scheme," Jakob Dahl Anderson, Report IT–146 ISSN 0105–854, Jun. 1994, Revised Dec. 1994, pp. 1–48.

"An Efficient Adaptive Circular Viterbi Algorithm for Decoding Generalized Tailbiting Convolutional Codes," Richard V. Cox, Car–Erik W. Sundberg; IEEE Transactions on Vehicular Technology, vol. 43, No. 1, Feb. 1994, pp. 57–68.

"On Tail Biting Convolutional Codes," Howard H. Ma; Jack K. Wolf, IEEE Transactions on Communications, vol. Com–34, No. 2, Feb., 1990, pp. 104–111.

"An Efficient Maximum Likelihood Decoding Algorithm for Generalized Tailbiting Convolutional Codes Including Quasicyclic Codes," Qiang Wang and Vijay K. Bhargava, IEEE Transactions on Communications, vol. 37, No. 8, Aug. 1989, pp. 875–879.

"Illuminating the Structure of Code and Decoder of Parallel Concatenated Recursive Systematic (TURBO) Codes," Patrick Robertson, IEEE, 1994, pp. 1298–1303.

"Near Shannon Limit Error–Correcting Coding and Decoding: Turbo–Codes (1)," Claude Berrou, Alain Glavieux, Punya Thitimajshima, IEEE, 1993, pp. 1064–1070.

"Optimal Decoding of Linear Codes for Minimizing Symbol Error Rate," LR Bahl; J Cocke; F. Jelinek; J. Raviv; IEEE Transactions on Information Theory, Mar. 1974, pp. 284–287.

"Near Optimum Error Correcting Coding and Decoding: Turbo–Codes," Claude Berrou; IEEE Transactions on Communications, vol. 44, No. 10, Oct. 1996, pp. 1261–1271.

"A Comparison of Optimal and Sub–Optimal Map Decoding Algorithms Operating in the Log Domain," Patrick Robertson; Emmanuelle Villebrun; Peter Hoeher; IEEE 1995, pp. 1009–1013.

"Terminating the Trellis of Turbo–Codes in the Same State," AS Barbulescu; SS Pietrobon, Electronics Letters 5th Jan., 1995 vol. 31, No. 1, pp. 22–23.

"Terminating the Trellis of Tubo–Codes," O. Joerssen; H. Meyr; Electronics Letters 4th Aug., 1994 vol. 30, No. 16, pp. 1285–1286.

"A Viterbi Algorithm with Soft–Decision Outputs and its Applications," Joachim Hagenauer; Peter Hoeher; IEEE 1989, pp. 1680–1686.

* cited by examiner